

II. TSPA Methodology

The TSPA Peer Review Panel's first report included a section entitled "Communicating the Repository Concept and How It Is Intended to Work." In this second report, the Panel expresses its views on the major objectives of the TSPA-VA; describes what it considers to be reasonable expectations for the outcomes of the TSPA; and suggests measures that can be taken to address the limitations of the TSPA process.

A. Objectives

The Panel considers that there are three major objectives for the TSPA-VA:

- To help DOE with its decision about whether to proceed with a license application;
- To identify the major sources of uncertainty and deficiencies in the understanding of how the repository will perform over the extended time periods anticipated to be required by EPA standard, so that the TSPA process can be improved; and
- To provide DOE and its contractors with an integrated tool for evaluating alternative designs and materials.

The first of these three objectives, the use of the TSPA-VA in making a decision to proceed with a license application, is an objective to which the Panel can contribute only indirectly at this time. The results that are currently available are not sufficiently defined for the Panel to focus its review on regulatory compliance. In addition, regulations do not yet exist against which the analyses can be compared. However, the Panel does note in this report those factors, components, and/or systems where the support for particular analyses and assumptions appears to be insufficient.

The second objective is the major focus of the Panel's review. As noted in the Preface, the Panel has directed its primary attention to the methods, data, and assumptions that have been developed or identified for the conduct of the TSPA-VA. The Panel's goals have been to note weaknesses that can be ameliorated through the use of more appropriate models and data, to seek clarification of the bases for certain of the analytical approaches and assumptions that have been used, and to evaluate the sensitivity analyses of alternative models and parameters and their associated uncertainties.

The third objective for the performance assessment is to assist in establishing a design that is both safe (from the perspective of exceeding regulatory goals) and analyzable. In this regard, the Panel notes that the current TSPA-VA review plan calls for analysis of many options associated with the reference design for the repository. This subject is discussed in more detail under "Design Options" in Section II. D.

B. Reasonable Expectations for the Outcomes of the TSPA

Projections of repository performance over the required extensive periods of time are highly uncertain. There are several factors that inherently limit the outcomes of such estimates.

- The time periods of the TSPA-VA extend to 10,000 or more years, with unknown changes occurring over that time (e.g., climate, locations of people and their sources of food and water). The time period is also long compared to that available for testing the corrosion rates of materials, thus making the extrapolation of materials performance uncertain.
- The site is heterogeneous, and movement of radionuclides occurs as a result both of water flow through fractures and its interactions with the rock matrix. The site cannot be characterized at a scale fine enough to define precisely the flow paths or material interactions.
- The system is complex and coupled. The interactions between heat, moisture, and the chemical environment, and the responses of the proposed repository to the associated mechanical stresses, are complicated and cannot be modeled with precision. Material performance will depend on the thermal, chemical, and hydrological environment as they evolve over time, yet material performance can also alter these conditions, e.g., corrosion byproducts from steel may affect temperature, water flow, colloid formation, and water chemistry.

Predictive Versus Descriptive Analysis

When the standard for the geologic disposal of radioactive wastes was being developed, EPA recognized the uncertainties associated with performance assessments over long time scales. For this reason, in its standard for spent nuclear fuel and high-level and transuranic radioactive wastes (which now applies to the Waste Isolation Pilot Plant (WIPP), but not to the proposed repository at Yucca Mountain), the EPA included in 40 CFR Part 191.13(a) the following statement regarding the degree of confidence that one must have that the containment requirements are met:

Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13(a) will be achieved. (U.S. EPA, 1985)

In contrast, the Executive Summary of the “Methods and Assumptions” document (CRWMS M&O 1997a) includes a statement that the TSPA-VA will result in a description of “the probable behavior of the repository in the Yucca Mountain geologic setting . . .” and that the TSPA-VA team plans to “Conduct total system analyses that will predict performance.” The Panel believes not only that such claims are unnecessary but also that they cannot be fulfilled. Even though the EPA standard no longer applies to the proposed repository, the Panel believes that the call for “reasonable expectation” that the containment requirements be met can serve as an indication that “... unequivocal numerical proof of compliance is neither necessary nor likely to be obtained.” The Panel recommends that the TSPA-VA team recognize these more modest expectations for what the TSPA can be expected to achieve.

Although the TSPA will provide a basis for an analysis of the probable behavior of the repository over an extended period of time, this goal can be achieved only through the identification of the relevant scenarios and the probabilities assigned to contemplated events. This will involve the characterization of the site, the identification of radionuclide release scenarios, the selection and application of relevant conceptual models, and the acquisition of the required input data. Each of these steps will have associated uncertainties. As such, any “prediction” of repository behavior need not be the purpose or necessary goal of the total system performance assessment.

The philosophical basis for such criticisms has been succinctly summarized by Oreskes et al. in a paper entitled, “Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences” (Oreskes et al. 1994). In their conclusion, the authors make a rather simple but compelling point:

In areas where public policy and public safety are at stake, the burden is on the modeler to demonstrate the degree of correspondence between the model and the material world it seeks to represent and to delineate the limits of that correspondence.

If the TSPA is described by its authors as “predictive,” then it will be taken to be a realistic representation, not an abstraction based on highly simplified models. In such a case, there may be insufficient consideration of the degree to which the model does not correspond to reality. Without consideration of any lack of correspondence, the value or utility of the TSPA may not be realized.

Beyond question, the models used in the TSPA will be reviewed critically by geoscientists, many of whom will have had extensive experience in modeling geologic systems, both modern and ancient. This experience will lead to skepticism if the claim is made that the behavior of the hydrogeologic or geochemical system can or will be predicted over long time scales. This skepticism is likely to be heightened by what appears to be the unwarranted application of the expert elicitation process. This skepticism may, in fact, be independent of the actual methods, content, and findings of the TSPA. It will arise simply because of the perception by geoscientists, true in some instances, that the TSPA team is insufficiently aware of the limitations of their tools.

Examples of the perspective described above have been provided in the Forum discussion in *GSA Today* (vol. 6, no. 5, May 1996), entitled, "Modeling Geology -- The Ideal World vs. the Real World". Only two months ago (October, 1997), the Geological Society of America sponsored a special symposium entitled, "Predictive Modeling in the Earth Sciences: Application and Misapplication to Environmental Problems."

Limitations of the Models

Significant errors in performance assessment may occur due to the selection of the wrong deterministic model for specific phenomena, to an incorrect analytical solution for the model, to an incomplete description of the system to be modeled, or to the fact that an "abstraction " may not capture the behavior of the system. Additionally, there always remains the possibility of non-linear behavior in complexly coupled systems. These points are readily illustrated by consideration of two important disciplines in the performance assessment of a repository -- hydrology and geochemistry.

Post-audits of hydrologic models used to assess changes in groundwater salinity (Konikow and Person, 1985) and groundwater level changes (Konikow, 1986), over periods as short as ten years, revealed large discrepancies between modeled and measured values. These discrepancies were due to conceptual errors in the model and/or a failure to anticipate stresses on the hydrologic system (Konikow and Patten, 1985).

Geochemical models have been no more successful in describing water-rock interactions. The evolution of groundwater compositions over time is difficult to predict, as are the phase assemblages formed during the alteration and weathering of even common minerals; particularly difficult to model are groundwater trace element compositions and their host phases (McKinley and Alexander, 1992). Further, geochemical models of even simple systems (e.g., O_2 fugacity set by sulfide equilibria) may not have unique solutions (Bethke, 1992); and despite impressive progress in quantitative analysis of the time-space transport of solutes and their reaction with minerals (Lichtner, 1993), the limiting conditions of such calculations make them difficult to apply with confidence (e.g., the models presume that the host rock is homogeneous and infinite). Other geochemical issues aside (see Nordstrom, 1992, for a summary), the compilation of thermodynamic data for the relevant actinide-bearing phases, e.g. uranium (Grenthe et al., 1992), has proven to be an enormous undertaking and many gaps and inconsistencies in the data remain. These inadequacies in the conceptual models or the associated data bases cannot be entirely overcome by the use of elicited expert opinion, because the expert opinion ultimately relies on some knowledge and appreciation of the conceptual models and the relevant data base.

These philosophical and practical limitations are compounded by the fact that the analytical process involves the use and coupling of complex models to assess conditions over extended periods of time. The TSPA team needs not only to ensure transparency and traceability of the analysis, but also to address the issues of analyzability and the

extent to which the outcomes of the TSPA are convincing and/or believable. Given the complexity of the system and the models used in its evaluation, transparency and traceability are difficult to achieve. In the absence of a carefully established basis for the submodels used in the TSPA, one may reasonably expect that the results of the projections provided by fully-coupled models will be questioned.

In summary, the challenging features of the present TSPA-VA are that: (1) the already complex models are coupled; (2) the models are being extrapolated into temporal and spatial scales that are well beyond experimental data bases or human experience; and (3) there is very little testing of the component submodels. Compounding the problem, there can be no test of the fully-coupled and extrapolated models used in the TSPA. Thus, the Panel recommends that attention be given to the suggestions that follow.

C. Interpretation of TSPA Results

Once the assessments have been made, interpretation of the TSPA results is difficult, in view of the inconsistent degree of realism versus conservatism that the TSPA contains. In the first interim report, the Panel discussed the importance of viewing sensitivity analyses from multiple perspectives and over differing time periods. At that stage, the Panel noted that an aspect of performance may not seem important when viewed from one perspective, but may be important on the basis of other performance measures or perspectives. For example, in the TSPA published in 1995 (TSPA-95) (CRWMS M&O, 1995), waste package performance was found to be unimportant in terms of peak dose based on a million years performance measure, but important based on a 10,000 year perspective.

A related point is that sensitivity analyses, conducted to identify which aspects of repository performance are most important from the perspective of selected performance measures, may be unable to provide sufficient information for analysts to distinguish those features that are truly important from those that are unimportant. While it may be possible to analyze some components and systems in a realistic manner, the analysis of others may, of necessity because of data limitations, have to be based on bounding and therefore unrealistic assumptions. This can lead to several problems:

- It will be difficult to assess the relative importance of components and systems analyzed under the two approaches;
- As in the case of sensitivity analyses, an unrealistic bounding analysis may, in some cases, indicate incorrectly that a particular feature of the site or design is unimportant to performance, while, in fact, it is important; and
- An analysis that is unrealistically optimistic may mask the actual sensitivities in some aspects of the performance of that system and/or component.

Where the required documentation has not been provided, the Panel is not in a position to support the use of a particular analytical model for that component and/or system. The identification of areas where the basis for model selection and improved documentation is needed will undoubtedly be expanded as a result of the ongoing technical exchanges between the Project team and USNRC staff. One document that does attempt to analysis the contribution to performance of the various components of the repository system is the *Waste Isolation Study* (CRWMS M&O, 1997d). The Panels comments on this report are provided in Appendix B.

As part of the iterative performance assessment cycle, the Project team has undertaken work where it judged that the conservative nature of the analysis should be corrected. The objective is to make the analysis more realistic, both where it will indicate that a particular concern is not as important as initial analyses implied, for example, volcanism, and where the unrealistic analysis failed to provide appropriate credit for some aspect of performance, for example, the TSPA-95 (CRWMS M&O, 1995) assumption that a waste package failed completely with the first pinhole leak.

The point of noting that the TSPA-VA will inevitably be an uneven mixture of bounding analyses and of more realistic assessments is two-fold. The first is to caution against overconfidence in the validity of the results of sensitivity analysis. The results of the TSPA and the associated sensitivity analyses need to be interpreted with judgment, and recognized as being conditional on many assumptions of varying validity.

The second is to comment, as in our first report, on the issue of analyzability. The Panel's message is that for a repository to be licensable, it must be analyzable. The issue of analyzability which was briefly discussed in Section II, Part A, above, is addressed in more detail in Section III in connection with several issues, notably with analysis of the thermal pulse and in Design Options, below, in connection with analysis of the effect of backfill.

In the Panel's view, there has been a tendency by the Project team to judge the benefits of selected components of the engineered barrier system (EBS) and waste package with insufficient technical review of whether the assumed contributions can actually be achieved. In the absence of sufficient supporting analysis or documentation, potentially misleading conclusions can be reached about the sensitivity of the performance of the repository due to failures of various EBS components. The treatment of drip shields, galvanic protection and cement linings provide examples. Drip shields are presumed to remain in place for extended periods and, hence, they are able to extend the life of the waste packages by preventing water access to them. Galvanic protection is presumed to extend the life of the waste packages by delaying the onset of localized corrosion of the inner barrier. Cement is presumed to remain in place for extended periods of time during which it will modify the composition of waters entering and leaving the drift. It is recognized that these issues are works-in-progress and further analysis is underway. The Panel will continue to monitor progress on these issues.

D. Addressing Limitations and Uncertainties

The project can be complimented for adopting two strategies to help with the TSPA analysis: (1) the use of time plots for particular realizations (Whipple et al., 1997); and (2) the use of subsystem measures, such as those utilized in the report “Description of Performance Allocation” (CRWMS M&O, 1996d). Both of these approaches can not only make the TSPA more understandable, but can also provide considerable insight into how the repository systems will operate (e.g., some systems, mainly in the near-field, contain or prevent radionuclide release and dispersion, while others, mainly in the far-field, result in dilution of radionuclide concentrations).

Additional steps that can be taken to address the limitations and uncertainties in the TSPA are discussed below.

Model Testing

The Panel recommends that the Project team investigate methods by which subsystem models can be explicitly tested. These might include:

1. Design of experiments to test specific results of the near-field models. As an example, one could ask if the stable phases actually form in laboratory experiments that are predicted by the geochemical codes?
2. Testing far-field models using the larger scale experiments in the Exploratory Studies Facility (ESF). As an example, has the ability of the computer codes to simulate the thermohydrologic response been critically tested? This can be done by making *a priori* predictions of the temperature, flow rate, and the spatial and temporal variation in the saturation in the three thermal tests: the Single Heater Test, the Large Block Test (both of which are currently underway) and the Drift Scale Test (which is scheduled to begin in early December, 1997). It would be particularly useful to: (1) identify the sets of parameters or variables that exert the largest influence on the response, based on modeling; (2) identify the sets of parameters or variables that exert the smallest influence on the response, based on modeling; and (3) define what constitutes an acceptable match between prediction and observation. The Panel notes that this last point, defining an acceptable match between predicted and actual performance, could be established through the use of a data quality objectives (DQO) approach.
3. Blind-testing of geochemical and hydrologic models in different geologic systems or localities. As an example, the European Community Project to study the Oklo natural reactors in Gabon has conducted a blind prediction modeling exercise in which five geochemical codes and 4 geochemical data bases were used to predict actual, measured groundwater compositions (which are not revealed to the modelers at the beginning of the exercise) (Duro and Bruno, personal communication). Of course, the geologic conditions around the Oklo reactors are different from the conditions at

Yucca Mountain, but one expects that the geochemical codes and thermodynamic data bases used to describe the geochemical behavior of trace element migration will generally be applicable in both cases.

4. Determination of whether the methodology used in the TSPA provides results that are consistent with natural systems. Natural systems are useful analogues because of their large scale, extreme complexity, and age. To the extent that the TSPA models provide results that are consistent with observations in natural systems, their use in the TSPA is more convincing. In some cases, the site itself can be used to test models.

Regarding the fourth point above, the Panel was impressed by the thorough analysis of the flow and transport models for Yucca Mountain as developed from ^{36}Cl studies and the effort to integrate these results with other data sets, such as tritium, ^{14}C , ^{137}Cs , plutonium and ^{99}Tc (J. Fabryka-Martin et al., 1997). In particular, we applaud the effort to predict the distribution of fast paths containing bomb-pulse ^{36}Cl in the planned East-West Drift. Successful predictions based on careful analysis can provide substantial confidence in the TSPA analyses.

Use of Expert Elicitation

A number of important expert elicitations have taken place within the project over the past year, and the Panel has had the opportunity to review some of them, including the elicitations on the probabilistic volcanic hazard, on waste-package degradation, on saturated-zone-flow issues, and on near field/altered zone coupled effects. The documentation package for each of these elicitations is extensive; as a consequence, the Panel has reviewed only parts of the extensive reports, even for the areas in which Panel members have an active interest.

Overall, the Panel is impressed with the use of an advanced methodology for these elicitations. The approach being used incorporates extensive interactions among the experts at all stages, and the process stimulates the participants to strive for, but not force, consensus. The Panel also finds merit with the aggregation process and with the way these elicitations have been documented, including the care with which the interpretations of the individual experts, along with the overall "results," were presented.

However, the Panel continues to be concerned about the possibility that expert elicitation could be misused or abused by the Project team. Given the success of some of the recent expert-elicitation exercises, there could be the temptation to use this approach in situations where the benefits are not large, or even where it is wrong.

Specifically, there are only a limited number of circumstances for which using expert elicitation is appropriate. These circumstances usually involve a technical field where there is considerable scientific work already in existence (either some useful scientific data, some attempts to develop models of the relevant phenomena, or both). Often the

issue is that the data or models may have unclear relevance to the problem at hand, and the cognizant experts in the particular field do not have a strong consensus about what the data mean or which modeling approach is correct.

While sometimes the lack of consensus has degenerated into a "dispute," often the situation is that there has not been any need within the community of experts to systematically evaluate the available evidence. The value of a properly executed expert elicitation under these circumstances is that it provides the Project team with the full, and fully documented, range of interpretations of the data or models currently considered valid or respectable. Such a process can also, if properly applied, direct the thinking of the experts toward the specific question(s) facing the project, including where the data or model(s) need to be applied and how. Through the process of being forced to interact on the subject(s) at hand, the experts can often resolve the conflicting interpretations and provide a more unified view than the Project team could reach on its own.

When there is no consensus among experts as to the validity or meaning of the data sets or models, the more typical approach is for a project team, such as that performing the TSPA for the proposed Yucca Mountain repository, to review all of the literature, to interact with all of the key experts individually (by correspondence, telephone, meetings), and then to resolve the situation themselves. This is the normal way of deciphering what's what. The value of expert elicitation is that, in some situations, the elicitation process, involving interactions among the experts themselves, can accomplish a much better job of resolving the lack-of-consensus situation than could be accomplished in any other way.

Thus, the Panel suggests that, when the circumstances are appropriate, there is significant value to be gained by a structured expert-elicitation process. It can provide the best up-to-date thinking of the experts, and that thinking can be directed toward the specific problem(s) that the TSPA team is facing.

The most important results from this process are the identification of the factual basis which the experts deem to be relevant to the issue and the definition it provides of the conclusions that can justifiably be reached on the basis of existing evidence. What an elicitation process cannot accomplish is equally important: (1) it cannot develop "data" or a substitute for data where none exist; (2) while it can enable the existing data to be evaluated, it often cannot permit them to be successfully "assembled" into a useful data set; and (3) if the issue is to select from competing models to explain the relevant phenomena, rather than to understand differences among data sets of varying relevance, the interactions among the experts may not be able to resolve which among the several models is "best."

What a well-executed expert elicitation can do, even if other goals are not met, is to provide the best up-to-date thinking of the various experts on the subject at hand. That is often of significant value.

The Safety Case

The viability of Yucca Mountain as a nuclear waste repository finally must rest on the evaluation of safety (expressed as some measure of radiation exposure to individuals or a critical population). The outcome of the TSPA provides the means for this evaluation; however, the inevitable complexity of the TSPA may obscure or even confound the safety analysis. As the Panel presently understands the fundamental safety case for the proposed repository at Yucca Mountain, it is one of “defense-in-depth”, that is, a series of barriers operating to different levels of effectiveness and over different time scales, intended to limit the concentrations of released radionuclides and subsequent radiation exposures to below a prescribed regulatory limit.

The “defense-in-depth” strategy, however, is unproductive when the “depth” consists of a large number of barriers of questionable value. At present, the repository design features the TSPA team is analyzing include a number of barriers whose effect may be substantial, but for which the effect is speculative and the uncertainty is large. The Panel has observed that the contribution to performance such barriers are expected to make fluctuates as the Project team struggles with fundamental design issues (e.g., canister material, galvanic protection, drip shields, fuel cladding as a barrier, length of the dry period, etc.). Minor contributions from each of these additional barriers can lead to a positive result for compliance with a regulation. However, such an approach adds complexity to the analysis, and this complexity may obscure a clear statement of the fundamental basis of the safety case. The issue is whether these additional elements of the repository system design are necessary to the case for safety, or whether they represent minor, but useful, redundancies in the system design.

Given the complexity of the TSPA, the Panel notes that the analysis indicates that the performance of the repository depends primarily on the functions and efficiencies of the major elements of the system. These are the:

- Durability of waste form;
- Canister lifetime;
- Delays and limitations in the contact of water with the waste; and
- Travel times to repository boundaries of radionuclides, as either dissolved or colloidal species.

These are the inherent four elements of the repository system that control the radionuclide concentrations that reach the accessible boundaries. These system elements can be grouped into two spatial and functional groups:

- Near-field: delay in the release and mobilization of radionuclides; and
- Far-field: transport of radionuclides, with associated delay and dilution.

The passive, undisturbed performance of these barriers provides the most solid basis for arguing that the system is sufficiently understood to provide confidence in assessments of its long term behavior. Such discussions should be presented in parallel with the more complex analysis carried forward within the TSPA-VA to ensure that there is a clear and useful understanding of the behavior of the repository system over time.

Additionally, the TSPA team should consider which type of abstraction (e.g., domain-based, process-based, dimensionality and response surface) is most appropriate for the type of phenomenon being modeled. As an example, the description of waste form degradation and dissolution should be based on the chemistry and physics of the corrosion of a solid in the presence of aqueous solutions. The abstraction should be process-based because, in this case, it is possible to test it by comparison of the calculated results with those derived from short term laboratory experiments, empirical field observations, and known principles of physics and chemistry. In contrast, a response-surface may be appropriate when little can be known about the phenomenon (e.g., the actual distribution of fractures in the unsaturated zone). The TSPA team should be organized to match the particular phenomena being modeled with the relevant, possible or testable abstraction methodology.

In the Panel's view, the confidence that the public can have in the TSPA results will, to a large degree, depend on how the analyses of the major elements of the repository system are conducted and presented. The four major elements listed above can be presented in a framework that includes the supporting models and their underlying physical and chemical principles, conformance with available laboratory and field data, experiences with similar models in comparable systems, and sensitivity analyses based on alternative plausible models. If this is done effectively, the strategy of "defense-in-depth" will have been applied successfully to the design and analysis of the proposed repository.

Design Options

There are currently a large number of basic design features of the repository system that remain as options or are undetermined. This situation can add significantly to the range of analysis to be covered and may compromise the relevance of the Reference Case for the TSPA-VA.

Some engineering design alternatives can be considered in the TSPA through a comparatively simple change in model parameters. For example, the choice of waste package materials can be evaluated through the use of different corrosion rates that are dependent on temperature and humidity. Other design alternatives, however, cannot be so readily incorporated into the TSPA analysis. Backfill as a component of the Engineered Barrier System is one example. The use or exclusion of backfill is a major design feature that has multiple and coupled effects on the design of other components and the response of the repository. Backfill significantly affects the thermal behavior. Radiation of heat from the packages pertains with no backfill, while conduction pertains with backfill.

Waste package temperature is affected. Water composition, distribution of water to the waste package, and radionuclide release to the surroundings can be affected. Rockfall effects also vary over a wide range depending on whether backfill is used.

As the backfill example illustrates, alternative engineering designs can lead to the need to analyze fundamentally different processes (e.g., thermal radiation versus conduction). As was previously discussed (Part C), care is needed to ensure that various options are considered on an equal basis, so that one does not incorrectly conclude that Option A offers better performance than Option B, when in fact the differences in projected performance are mostly due to the use of comparatively optimistic analytical methods and assumptions for Option A in comparison to those for Option B.

Use of Data and Models From Outside the Yucca Mountain Project

Although the Yucca Mountain site and the proposed repository have many features unique to the U.S. program (the mixture of defense and commercial wastes; oxidizing conditions for spent fuel disposal; repository in an unsaturated flow regime, etc.), much could be gained from reviews of, and participation in, the programs of other countries and in interchanges with experts in the scientific disciplines relevant to the issues requiring resolution. The evident decision (partly based on limitations in time and resources) to restrict such interactions may prove costly in the long run in that the Project team will unnecessarily duplicate studies that have already been completed and published. Additionally, the general scientific credibility of the project requires participation and publication in the appropriate scientific forums and journals.

As examples:

1. The data base used to develop the response surfaces to describe spent fuel corrosion is restricted to data developed at U.S. national laboratories. There is an extensive literature on the corrosion of uranium oxides in a variety of chemical and geochemical environments. Even if these data are not used explicitly in the response surface abstraction, they can be used to test the general applicability of the response surface approach.
2. Although we were presented with several white papers on the durability of fuel cladding, the Panel notes that there is an extensive, recent literature on the properties of cladding that was not included. Although the white papers focused on the properties of cladding in the disposal environment (for which little is known), there is a substantial literature on the formation of hydrides and resulting embrittlement as a function of the fuel history (irradiation and thermal). This literature will be available to, and reviewed by, critics of the project; the TSPA should endeavor to incorporate as much as is known or published on this issue into its own analysis.
3. As discussed above in Section B, "Limitations of the Models," one important issue will be the question of whether, and to what extent, coupled processes can be modeled

satisfactorily. In Europe, the FEBEX Project (a collaboration between Switzerland and Spain at the Grimsel test site) has the purpose of developing and testing “. . . conceptual and numerical models for the thermal, hydrodynamic and geochemical (THG) processes expected to take place at the engineered clay barrier of the HLW repository as a consequence of the induced thermal field and water flow.” In a recent presentation (J. Samper et al., Materials Research Society symposium on “Scientific Basis for Nuclear Waste Management,” 1997), the authors noted, “The current state-of-art on coupled THG modeling does not allow a fully detailed and reliable numerical prediction of the FEBEX *in situ* experiment mainly due to: (1) the lack of a sound conceptual model for the hydrochemical interactions taking place at the water-clay interface for compacted bentonites and (2) the inability of current THG codes to cope with *the simultaneous flow of water and gas through highly reactive and complex porous media under highly non-isothermal conditions.*” [italics added]. Although the present design for the proposed repository at Yucca Mountain does not include backfill, the project must be interested in the simultaneous flow of water and gas through highly reactive and complex porous media under highly non-isothermal conditions.

4. As discussed in Section IV, Biosphere, Doses, and Health Risks, one of the radionuclides for which dose assessments are being made is ¹²⁹I. In some cases it is estimated to represent one of the major contributors to dose for members of the public who may live near the proposed repository. Although such assessments may be mandatory under terms of the anticipated EPA standard, the TSPA team appears to be pursuing this task with little consideration of how organizations, such as the National Council on Radiation Protection and Measurements (NCRP), view the health impacts of this radionuclide. On the basis of its reviews, the NCRP has concluded that “¹²⁹I does not pose a meaningful threat of thyroid carcinogenesis in people.” In a similar manner, the TSPA team does not appear to have considered the range and magnitude of the uncertainties incorporated into the dose conversion factors that they will be using in developing their “Biosphere Dose Conversion Factors.” The National Research Council Committees on the Biological Effects of Ionizing Radiation and on an Assessment of CDC Radiation Studies have been careful to point out that these factors were developed for purposes of radiation protection, not dose assessment. As such, they contain large degrees of conservatism. Also contributing to conservatism is the use of the concept of committed dose in estimating the lifetime doses to members of exposed population groups. According to the NCRP, 50% or more of the doses estimated on the basis of this concept will never occur. These represent additional examples where there appears to be a need for the TSPA team to become more familiar with information and data from other groups who are addressing topics relevant to the performance assessment process.

E. TSPA Performance Measure

The EPA standard for Yucca Mountain is not yet available, nor is it clear what the USNRC will do regarding revisions of its regulations. In place of defined standards and regulations, the DOE has established an interim post-closure performance measure as a placeholder until the actual standards exist. The assumption implicit in the DOE interim performance measure is that the eventual EPA standard will include a limit on the dose

rate to an individual of specified habits (i.e., the consumption rates of food and water and whether they are produced locally or imported) at a specified distance from the repository for a specified interval of time. In the interim performance measure provided by DOE, the dose rate limit is 25 millirem (mrem) per year to the average individual in Armagosa Valley, measured 20 km down-gradient from the repository, for 10,000 years after closure.

The absence of an EPA standard does not appear to the Panel to pose an operational problem to the Project or TSPA teams, as long as the above assumptions about the nature of the EPA standard prove to be correct. Based on other EPA standards, e.g., 40 CFR 191, the final standard may also include a groundwater protection provision in addition to an individual dose rate limit. Because the TSPA analysis of dose rates is based on estimates of groundwater concentrations, a groundwater protection requirement would not increase the analytical requirements of the TSPA. Whether such a requirement would increase the stringency of the standard depends on the actual limits imposed and on the methods specified for compliance analysis.

The EPA standards for WIPP (10 CFR 191 and 194) contain requirements on retrievability that may reveal the likely thinking of EPA on this subject for the proposed repository at Yucca Mountain. As the Panel reads the WIPP requirement, it is not necessary that waste emplaced deep underground be retrievable forever, or relatively inexpensively, or relatively easily -- only that retrievability of the waste not be essentially precluded by the emplacement scheme in the "early" period after emplacement. In the Panel's view, the likely retrievability requirement, if it is included and interpreted as in the past, will allow substantial leeway to the Project team in both design and analysis. For example, various backfill options can be considered.

The fact that the USNRC regulations will be revised poses a more complex analytical issue for the TSPA team. The current USNRC requirements, 10 CFR Part 60, include subsystem performance requirements. Depending on whether or how such subsystem requirements are retained, additional analyses may be required.

F. Enhancing the Utility of the TSPA-VA

There are a number of actions that can be taken to enhance the utility of the TSPA-VA. Those discussed in this section include the recognition of:

- Multiple objectives of the analysis (to inform a decision regarding whether to proceed to licensing, to identify data and analyses to improve future analyses and reduce their uncertainties, and to assist with design choices).
- Reasonable expectations for, and limitations in, what the TSPA-VA can do, given the complex, coupled processes and long time periods of interest.

- The availability of tools to address the analytical limitations, for example, model testing, the appropriate use of expert elicitation, and the proper selection and evaluation of various barriers selected as part of the "defense-in-depth" safety case. This includes taking advantage of any and all opportunities to test and evaluated the models being applied as part of the TSPA process, and recognizing the value of, and limitations on, the use and application of the expert elicitation process.
- Relevant studies and data that have been, and are being, generated by other groups throughout the world that have direct applicability to the TSPA for the proposed Yucca Mountain repository.